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THE RESISTANCE OF ANTHRACITE TO MECHANICAL AND THERMAL SHOCK

Coulsen Charles Wright

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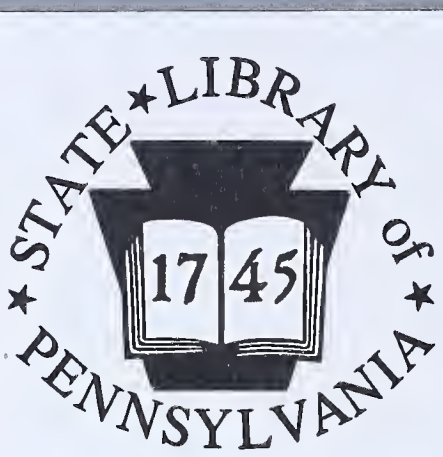

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THE PENNSYLVANIA STATE COLLEGE BULLETIN

Mineral Industries Experiment Station Bulletin 31

The Resistance of Anthracite to Mechanical and Thermal Shock

C. C. WRIGHT, L. L. NEWMAN, and A. W. GAUGER

This research program was sponsored jointly by the Commonwealth of Pennsylvania and the Anthracite Institute and carried out under the supervision of the State Department of Mines.

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The Resistance of Anthracite to Mechanical and Thermal Shock

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Gift of

Ruth W. Mednick

School of Mineral Industries
The Pennsylvania State College
State College, Pennsylvania
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to mechanical and thermal

ACKNOWLEDGMENT

THIS investigation was made possible through enactment by the 1939 General Assembly of the Commonwealth of Pennsylvania of a bill sponsored by Senator Robert M. Miller appropriating funds to the School of Mineral Industries of The Pennsylvania State College for a program of co-operative research on anthracite and bituminous coal. The program was to be carried out under the supervision of the Department of Mines of the State of Pennsylvania and was contingent upon the coal industry's providing a like and matching sum. The anthracite industry through the Anthracite Institute has co-operated fully in this program. Problems for investigation were selected by the Anthracite Research Advisory Committee the membership of which follows:

Name	*Affiliation*
John Ira Thomas	Secretary of Mines (to July 1940)
Richard Maize	Secretary of Mines (from December 1940)
Joseph J. Walsh	Deputy Secretary of Mines
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H. G. Turner	Research Engr., Anthracite Equipment Corp.
J. F. K. Brown	Asst. Gen. Mgr., Engr., Hudson Coal Co.

The authors are deeply indebted to the advisory committee for constructive criticism and active assistance throughout the course of this work.

Appreciation and thanks are extended to the several companies and individuals who supplied the coal samples used in these tests, and to R. J. Grace, W. L. Johnston, and E. F. Williams for very material assistance in analytical, experimental, and photographic work during the course of these studies.

FOREWORD

This bulletin presents a report of some of the results obtained in the research program on anthracite, sponsored jointly by the Commonwealth of Pennsylvania and the Anthracite Institute, under Act No. 392 of the 1939 General Assembly and carried out in Pennsylvania's School of Mineral Industries and Experiment Station under the supervision of the State Department of Mines.

The anthracite and bituminous coal industries form the keystone of Pennsylvania's industrial development. Together they have carried a large share of the burden of the State. For more than a decade they have been harassed by economic conditions and have suffered from declining markets and loss of revenue. The present program of research was initiated in the belief that research was one means of alleviating the situation.

For various reasons the work did not get under way in full force until the second quarter of the biennium. Since that time excellent progress has been made on both the anthracite and bituminous coal research programs. Further reports of progress on the different phases will be presented to the citizenry from time to time.

The anthracite program consists of two projects. One of these relates to the study of the use of large sizes of anthracite for the generation of water gas. The second is concerned with the manufacture of active carbon from anthracite. In the course of the study of the first project it became apparent that a laboratory study of the behavior of anthracite on exposure to high temperatures had first to be investigated. The present bulletin shows the results of this investigation.

During the past year successful experiments have been carried out in two city gas plants. The results of these experiments will be reported in two subsequent bulletins.

It is most fortunate that these studies were instituted when they were, since their results are important from the standpoint of national defense. The use of anthracite for generator fuel is leading to further studies on anthracite as a cupola fuel. Coke can be released for blast furnace utilization since anthracite, when properly used, is eminently successful as a generator fuel in water gas manufacture. Further investigations should lead to other forms of utilization.

This program is an excellent example of the much desired cooperation between industry and government. It makes full use of the special facilities of the Commonwealth's Land Grant College. The Industry, the Commonwealth, and the College will all gain through such a program.

Richard Maize
Secretary of Mines.

INTRODUCTION

PRIOR to 1920, an appreciable tonnage of the generator sizes of anthracite—grate, broken, and egg—found a ready market as fuel for the production of water gas, and for the peak year of 1919, well over one million tons of these sizes were used by the water-gas industry. This tonnage fell precipitously during the 1920's and reached a minimum of approximately 33,000 tons in 1932. During the past decade slight gains have been made by the industry in regaining this market, but the peak of 82,000 tons supplied to the water-gas industry in 1939 is still far short of the former consumption and represents but slightly more than 5 per cent of the total solid generator fuel used throughout the normal anthracite marketing territory.

Numerous causes contributed toward this loss of the generator fuel market, among which may be mentioned the labor difficulties of the early twenties, lack of uniformity of product, lack of interest in the market on the part of producing companies, and excess coke-producing facilities engendered by the war effort of 1916-18. At the present time, however, these causes no longer exist and given the necessary technical information the industry is in a favorable position to regain at least a portion of the lost market.

In an endeavor to secure this technical information, a co-operative research program was started in October 1939 at The Pennsylvania State College under the joint sponsorship of the Commonwealth of Pennsylvania and the anthracite industry. This program had as its objective a study of the use of anthracite in gasification processes, and especially as generator fuel for the manufacture of water gas.

Before initiation of any experimental work, a field survey was made to determine, if possible, those properties and characteristics of anthracite which are of major importance to the water-gas industry. Many plants were visited and water-gas operators interviewed. Several plants in Pennsylvania were found to be using anthracite regularly as generator fuel with excellent results and several operators were found who considered anthracite to be a superior fuel for this purpose. Other operators were found, however, who questioned the ability of anthracites to withstand satisfactorily the combination of thermal and mechanical shock to which a fuel is subjected in a modern water-gas machine.

As a result of this survey, it was decided that a study should be made of the mechanical and thermal stability of a variety of anthracites in an endeavor to clarify the situation with respect to possible decrepitation of this fuel in a water-gas generator. Although several other phases of the water-gas project are being

investigated, including full-scale tests in plants using both the light and heavy oil processes, the present paper deals primarily with studies which have been completed on the stability of anthracite under conditions of shock comparable to those experienced by generator fuel.

Literature Survey

Determination of the size stability toward mechanical shock is a well-established procedure and requires no extensive review of the literature pertaining thereto. In 1923 a standard method of determining the size stability of coke[1] was established by Committee D-5 of the American Society for Testing Materials, and in 1937 a tentative procedure was adopted by the same committee for use on coal[2]. Briefly, the method consists of dropping a 50-pound charge of the material to be tested from a height of 6 feet in a definitely prescribed manner onto a cast iron or steel plate. For coke, four such drops are prescribed and for coal, two drops. The material is then screened, using for coke square-mesh openings and for coal round-hole screens, to determine size degradation. The results may be expressed in terms of the percentage of material remaining upon a screen of given opening or as size stability defined as follows:

$$\text{Size stability} = \frac{(100)\ (s)}{S}$$

where

s = Σ (Average screen opening factor) x (Percentage by weight after shatter between the screen limits for which the size factor is obtained).

S = Σ (Average screen opening factor) x (Percentage by weight before shatter, between the screen limits for which the size factor is obtained).

In regard to the size stability of anthracite toward thermal treatment, examination of the technical literature reveals a surprising dearth of information. That this factor was of interest to water-gas operators as early as 1906 is revealed by "Answers to Fourth Series of Questions, Section 1908, Practical Class, American Gas Light Association"[3] where the following statement appears: "The quantity of gas that can be made depends largely upon the amount of fixed carbon in the coal (anthracite) and also upon the hardness and ability to withstand handling and weight of fuel above it in the generator without breaking up into small pieces. The rate at which gas can be made is influenced by the ability of the coal to

[1]A.S.T.M. Standards on Coal & Coke, D141-23 (1923).
[2]A.S.T.M. Standards on Coal & Coke, D440-37T (1937).
[3]Proc. Am. Gas Inst., *1*, 128 (1906).

resist crushing without which the fire cannot be kept in good condition for gas making....."

Pines[4] has studied the "cracking" of anthracite when heated to 850-900° C by means of X-ray technique, and concludes that "cracking" is due to the presence of inclusions in the coal which causes cleavage to occur under the conditions of temperature and pressure found in blast furnaces. Blayden, *et al*,[5] likewise using X-ray technique, studied the crystalline growth of Welsh and Southern Field anthracites when gradually heated to a temperature of 2000° C and reports that up to 700° C the process is primarily one of aromatization and consists essentially of lateral extension of the planes of the graphite crystallites. With Pennsylvania anthracite the layers started lateral growth at the expense of the number of planes beginning about 400° C and continued growth up to a temperature of 900° C. Evidence was obtained of anisotropic expansion between the layers of the graphite crystallites tending to disrupt the structure. The authors suggest that this disruption may account for the phenomenon of decrepitation and may possibly be explained as resulting from liberation of hydrogen ions adsorbed between the layer planes of the graphite crystallites. This explanation is supported by evidence that gas evolution and disruption occur over the same temperature range of 500 to 900° C. Above 900° C thermal recrystallization sets in with increase of the graphite crystallite perpendicular to the planes, but apparently with no further disruption of the relative position of the planes.

Miroshnichenko[6] and Skomorochov[7] described the results of slow heating of Russian anthracites over a period of about 18 hours up to temperatures of about 1400° C and the production thereby of what they term "Thermoanthracite." This material has a reduced water and volatile matter content and is reported to be considerably higher in resistance to compression. Increases as high as 300 per cent are reported by Miroshnichenko. Nothing is stated, however, regarding the stability of the product toward mechanical shock.

It appears, therefore, that although attempts have been made to determine the cause of decrepitation and to a limited extent to eliminate this phenomenon, no published information appears to be available which describes a satisfactory method for evaluating this characteristic.

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[4]Pines, B., Domez, No. 1 & 2, 41-7 (1932).
[5]Blayden, H. E., Riley, H. L., and Taylor, A., *Am. Chem. Soc.*, 62, 180 (1940).
[6]Miroshnichenko, G. K., *Vestnik Standertizatsii 13* No. 11, 5, No. 12, 7 (1938).
[7]Skomorochov, S. A., *Norostic Tekhniki* 7 No. 7, 36 (1938).

REPORT ON THE DECREPITATION OF ANTHRACITE RESULTING FROM THERMAL AND MECHANICAL SHOCK

In view of the fact that no accepted test was available by which decrepitation could be quantitatively determined, it was necessary to develop such a test. Since the objective was to determine the stability of anthracites when subjected to the conditions experienced in a water-gas generator, the test herein described simulates as closely as possible these conditions.

A critical examination of the modern water-gas process showed that the coal in a water-gas generator is subjected to substantially the following treatment: Cold coal is charged suddenly into a hot generator, the exposed walls of which are at a temperature in the vicinity of 1600° F, and falls a distance of 4 to 8 feet onto a bed of coal, the upper surface of which is at a temperature of approximately 1400° F. The machine then operates with alternate "blow" and "make" periods for about one hour before refueling. During this period the coal last charged is exposed to contact with hot reducing gases and attains a temperature of about 1400° F by the end of the last blasting period before refueling. During this operation moisture and varying amounts of volatile matter are eliminated with accompanying stresses due to the physical and chemical changes involved; differential expansion caused by the large thermal gradient throughout each lump of coal and mineral matter produce added stresses. This entire combination of stresses contributes toward the breakdown of size structure that has been called thermal decrepitation. At the end of the coaling to coaling period a fresh charge of cold coal is dropped on top of this thermally decrepitated coal and subjects it to a mechanical stress which, if the thermally treated coal has been badly weakened, may result in severe size degradation.

Laboratory Procedure

The raw coals as received from the collieries are carefully sized in the laboratory to 5″ x 4″, 4″ x 3″, and 3″ x 2″ using square-hole screens and these fractions, used for subsequent tests on thermal and mechanical stability, are designated throughout this paper as grate, broken, and egg. Although this square-hole sizing does not duplicate exactly the Anthracite Institute round-hole screen standards of $6\frac{1}{8}$″ x 5″, 5″ x $3\frac{3}{4}$″, and $3\frac{3}{4}$″ x $2\frac{7}{16}$″ for grate, broken, and egg coal, nevertheless, between 70 and 90 per cent of each of the coals received fell into the size classification adopted for this investigation. Square-hole rather than the standard round-hole screens were selected because water-gas fuels are generally sized on the square-hole series.

Two 25-pound charges of sized coal are placed in mesh baskets and each basket placed in a pot furnace which has previously attained an equilibrium temperature of 1600° F as measured by a thermocouple placed at the center of the furnace. The charge is then blasted with hot reducing gases for one hour at the end of which period the thermocouple at the center of the charge records

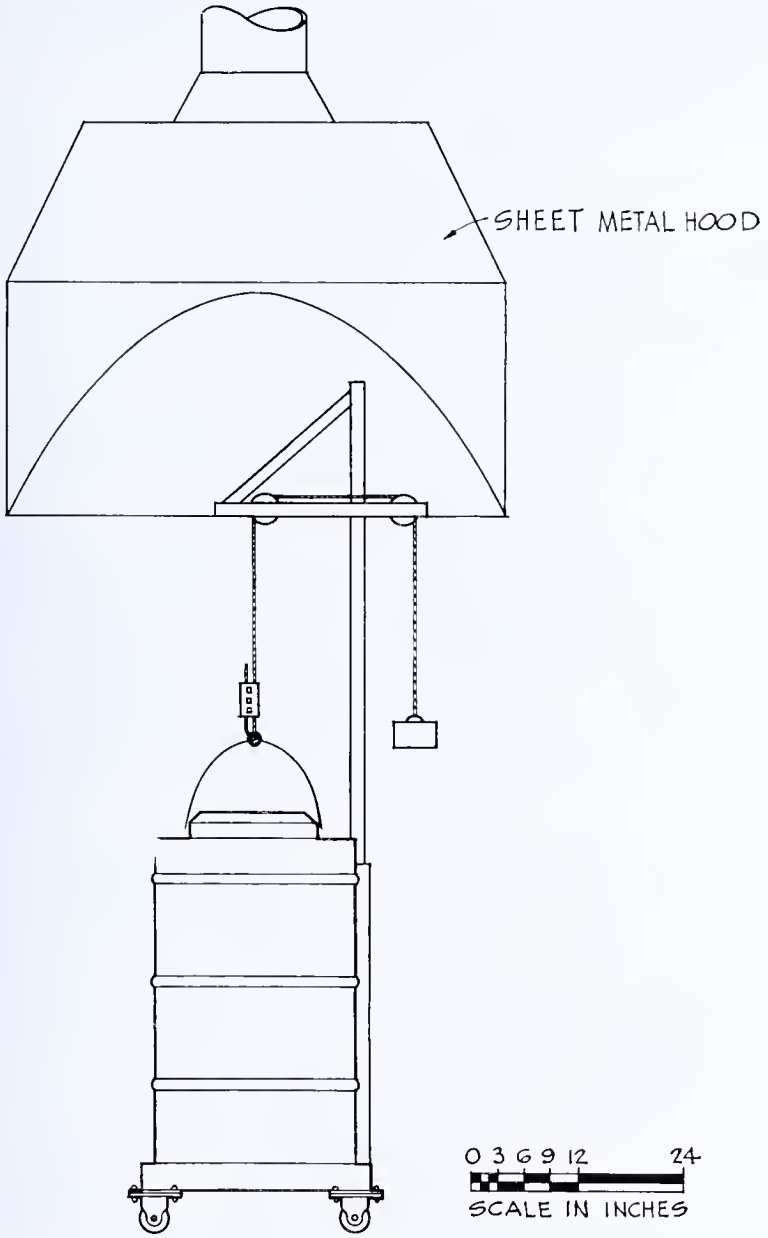


Fig. 1

General Assembly of Decrepitation Furnace

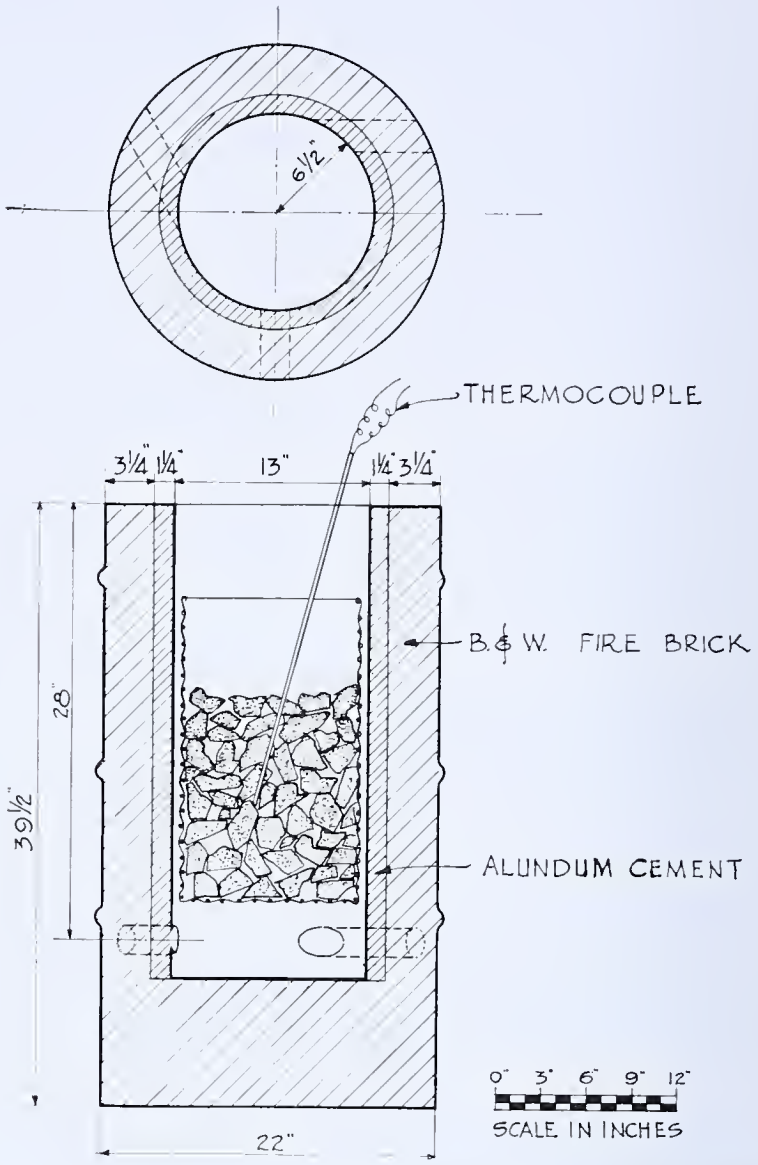


Fig. 2
Detail of Decrepitation Furnace Showing Basket with Charge

a temperature of approximately 1400° F. The baskets are then removed and dry quenched. When cool, the coal is carefully removed from the baskets and screened to determine the decrepitation resulting solely from thermal shock. The entire thermally treated charges from both baskets are then combined and drop-shattered according to the standard A.S.T.M. drop-shatter procedure[2] using two 6-foot drops. The material is screened after a single drop and again after a double drop to determine the degradation resulting from varying degrees of mechanical shock.

Fifty-pound charges of original coal are drop-shattered by the same A.S.T.M. drop-shatter procedure, and screened, to determine stability of the coal to mechanical shock only.

Apparatus

A brief description of the apparatus used in the decrepitation test appears in the following paragraphs.

Furnace.—A diagramatic sketch of the general furnace assembly is shown in Fig. 1, and in Fig. 2 is shown a cross section of the furnace and coal charge. The furnace consists of a 55-gallon oil drum with top removed, the inside of which is lined with a $3\frac{1}{4}$-inch layer of B. & W. No. 28 insulating fire brick plus a $1\frac{1}{4}$-inch layer of alundum cement. The furnace is closed by means of a 3-inch built-up refractory top fitted with ports for discharge of exhaust gases. Three gas burners fired with 525 Btu carbureted water-gas arranged as shown supply the necessary heat and by firing with a deficiency of air gave a satisfactory reducing atmosphere in the furnace.

Baskets.—The baskets are fabricated from 2-mesh, 8-gauge iron wire screen bent into the form of a cylinder 11 inches in diameter and 20 inches high closed at the base with a screen of the same material.

Drop-Shatter Apparatus.—The drop-shatter apparatus is the standard equipment described in "A.S.T.M. Standards on Coal & Coke."[1, 2]

Screens.—U. S. standard square-mesh screens were used and consisted of the following sizes: 5″, 4″, 3″, 2″, $1\frac{1}{2}$″, 1″, $\frac{3}{4}$″, $\frac{1}{2}$″, $\frac{3}{8}$″, and No. 4 mesh.

Temperature Measurement.—Temperatures are determined with a shielded chromel-alumel 18-gauge thermocouple and portable potentiometer.

Coals Investigated

Anthracites from all the major anthracite fields and from most of the mining districts of these fields have been investigated and are listed together with proximate analyses in Table 1. Except where specifically stated to the contrary, samples were of freshly secured coal which were subjected to test within a week or so of receipt. In three instances, two coals were investigated from the same mining districts because of reported differences in the character of the coal. Only three sizes of coal were investigated—grate, broken, and egg—because these are the sizes now supplied for water-gas manufacture. Where possible all three sizes were secured from the same colliery, but in several cases nothing larger than egg was being produced. Also included in Table 1 are proximate analyses of the coals after subjection to the thermal treatment described in the test procedure. Analyses were obtained in the case

Table 1

Source and Analysis of Coals

Laboratory Sample Number	Field	Remarks Size	Remarks Condition	Proximate Analysis Per Cent as Received — Original Coal Water	Volatile Matter	Fixed Carbon	Ash	After Thermal Treatment Water	Volatile Matter	Fixed Carbon	Ash
18	Northern	Grate	Hard structure	2.7	4.4	89.3	3.6	1.4	3.3	90.7	4.6
17	Northern	Broken	Hard structure	2.9	4.9	88.0	4.2	1.8	2.7	91.2	4.3
20	Northern	Grate	Checkered structure	2.7	5.7	83.6	8.0	1.3	3.8	89.0	5.9
19	Northern	Broken	Checkered structure	2.2	5.8	84.8	7.2	2.0	3.2	87.8	7.0
13	Northern	Broken		2.3	4.9	83.9	8.9	1.0	2.6	88.9	7.5
14	Northern	Egg		2.8	5.4	84.7	7.1	1.0	2.8	86.8	9.4
7	Northern	Broken		2.2	5.8	82.0	10.0	0.5	3.8	85.5	10.2
7A	Northern	Broken	6 months stored	—	—	—	—	—	—	—	—
9	Northern	Egg		1.8	5.5	83.4	9.3	1.1	3.1	86.1	9.7
9A	Northern	Egg	6 months stored	—	—	—	—	—	—	—	—
10	Eastern Middle	Broken		3.3	3.2	84.5	9.0	0.9	2.1	89.4	7.6
11	Eastern Middle	Egg		3.4	3.1	86.9	6.6	0.9	2.3	89.2	7.6
11A	Eastern Middle	Egg	4 months stored	—	—	—	—	—	—	—	—
3	Eastern Middle	Egg		4.0	3.3	87.0	5.7	0.7	2.1	90.4	6.8
3A	Eastern Middle	Egg	6 months stored	—	—	—	—	—	—	—	—
5	Western Middle	Broken		2.9	4.2	84.0	8.9	0.5	2.3	88.3	8.9
5A	Western Middle	Broken	6 months stored	—	—	—	—	—	—	—	—
6	Western Middle	Egg		2.7	3.6	85.7	8.0	0.4	2.7	89.1	7.8
6A	Western Middle	Egg	6 months stored	—	—	—	—	—	—	—	—
16	Western Middle	Broken		2.5	5.3	84.4	7.8	0.8	3.5	89.1	6.6
15	Western Middle	Egg		2.7	5.1	84.9	7.3	0.7	3.6	88.5	7.2
8	Southern	Egg		2.6	3.9	85.9	7.6	0.8	2.6	87.9	8.7
12	Southern	Egg		2.6	3.0	88.4	6.0	0.9	2.0	90.7	6.4
1	Southern	Egg		3.1	3.7	87.7	5.5	0.6	2.1	91.5	5.8
23	Southern	Grate		—	—	—	—	—	—	—	—
24	Southern	Broken		0.8	8.6	79.5	11.1	0.7	3.9	84.5	10.9
22	Southern	Egg		—	—	—	—	—	—	—	—

of both the original and thermally treated coals by grinding the entire 50-pound sample used for test and quartering according to accepted A. S. T. M. sample methods. All analyses were made according to accepted A.S.T.M. procedures.

Presentation of Data on Size Stability

Screen analyses data for drop-shatter of the original coal for the thermally treated coal and for drop-shatter of the thermally treated coal are shown in Table 2. Data were not secured in all cases for screen analyses after a single drop of the thermally treated coal, but sufficient data are presented to indicate the relationship existing between the single and double drops. Photographs of a few of the actual samples are shown in Figs. 3, 4, and 5 for original drop shatter, *A;* thermal treatment, *B;* and double drop-shatter of the thermally treated coal, *C*. In Table 3 are presented data for screen analyses on original coals subjected to four successive drops in order that a comparison may be made between published data on size stability of coke and typical data for anthracite.

Three factors relating to the size stability of a coal are of importance in a generator fuel, namely, stability toward handling of the original coal, stability toward thermal shock, and mechanical stability of the thermally treated coal.

Examination of the photographs shown in Fig. 3, 4, and 5 shows the actual number of pieces of coal which survive each type of treatment without size degradation. The same data on a weight percentage basis are shown in Table 2. Considerable variations were found among the coal in the number of original pieces in a 50-pound charge: for the grate size the number varied between 11 and 20, for broken between 32 and 41, and for egg between 54 and 112 pieces. As will be shown later, these variations are of some significance in water-gas operation, but other factors are generally of more consequence.

The data and pictures for the *A* treatment illustrate only the relative stability of the various samples toward mechanical shock when subjected to identical treatments and must not be interpreted as indicating specifically the amount of breakage these coals will undergo at any given plant because the handling treatment varies so markedly from plant to plant. They are, however, indicative of the degradation possible when extremely severe handling occurs.

The data and pictures for *B* treatment show the distribution of sizes resulting solely from thermal treatment as outlined in the standard procedure. For up-run and back-run sets, the thermal

Table 2

Screen Analyses of Coals from Various Treatments

(Weight Percentage)

Laboratory Sample Number	Treatment	5" x 4"	4" x 3"	3" x 2"	2" x 1½"	1½" x 1"	1" x ¾"	¾" x ½"	½" x ⅜"	⅜" x 4 Mesh	−4 Mesh
13	*A*	63.0	15.8	6.7	6.0	2.5	1.7	1.5	0.7	1.3	0.8
	B	21.2	11.9	23.0	10.9	16.7	8.8	5.2	1.6	1.0	0.6
	C'	0.0	0.0	16.4	17.1	29.3	16.8	10.5	3.9	3.5	2.5
	C'''	0.0	0.0	8.5	15.8	29.3	20.1	12.6	5.0	4.9	3.8
17	*A*		65.0	17.8	5.1	5.0	2.2	1.7	0.9	1.3	1.1
	B		25.5	25.6	14.0	17.4	9.7	5.4	1.2	0.7	0.5
	C'		2.0	14.3	12.7	33.5	16.8	11.3	3.8	3.2	2.4
	C'''		1.8	8.2	11.7	31.8	19.9	13.4	4.9	4.6	3.7
20	*A*	64.6	13.7	7.9	2.8	3.3	1.6	1.9	0.9	1.4	1.9
	B	57.1	13.9	10.2	4.1	5.3	3.3	2.8	1.4	1.1	0.8
	C'	9.4	9.9	19.3	11.7	16.6	10.0	9.0	4.4	5.3	4.4
	C'''	4.2	9.4	14.4	12.5	12.1	12.3	12.4	6.6	8.9	7.2
19	*A*		54.2	25.6	4.5	4.5	2.4	2.4	1.5	2.4	2.5
	B		59.8	19.3	5.8	5.7	3.3	2.8	1.3	1.2	0.8
	C'		19.6	15.7	12.5	17.1	10.7	9.7	4.7	5.5	4.5
	C'''		12.8	11.1	9.2	19.3	14.0	12.3	6.5	7.8	7.0
13	*A*		70.9	12.4	5.8	3.2	2.4	1.6	1.0	1.6	1.1
	B		66.1	11.5	10.9	5.8	3.0	1.5	0.5	0.4	0.3
	C'''		7.2	16.8	14.5	20.3	15.6	10.9	4.4	4.3	6.0
14	*A*			31.2	5.5	5.2	2.5	1.6	1.1	1.7	1.2
	B			82.2	7.7	5.9	2.5	1.0	0.3	0.2	0.2
	C'''			27.9	13.9	24.5	11.4	8.9	4.4	5.6	3.4
7	*A*		62.8	16.2	9.1	4.9	1.9	1.7	0.9	1.4	1.1
	B		78.2	12.7	3.6	3.6	1.1	0.4	0.3	0.0	0.1
	C'''		12.9	22.5	11.3	25.7	10.7	7.4	3.0	3.3	3.2
9	*A*			72.0	10.8	7.9	2.5	2.6	1.1	1.4	1.7
	B			75.0	12.1	7.0	3.4	1.6	0.4	0.3	0.2
	C'''			24.0	12.2	24.9	16.6	10.0	4.1	4.5	3.8
10	*A*		82.5	5.5	2.7	3.1	1.5	1.2	0.9	1.2	1.4
	B		72.6	17.6	5.3	2.4	0.9	0.4	0.4	0.1	0.3
	C'''		6.3	24.1	15.9	27.1	11.0	6.2	2.9	3.4	3.1
11	*A*			78.1	7.0	4.5	2.3	2.4	1.6	2.5	1.6
	B			93.6	3.3	2.0	0.5	0.2	0.2	0.1	0.1
	C'''			37.1	20.7	21.2	8.6	4.5	2.2	2.6	3.1
3	*A*			72.5	11.9	5.6	2.7	2.5	1.4	2.1	1.3
	B			93.5	2.8	2.7	0.7	0.1	0.1	0.0	0.1
	C'''			21.4	20.2	36.1	9.8	5.4	2.1	2.7	2.3

5	*A*	—	66.8	20.3	3.2	3.0	2.0	1.3	0.8	1.2	1.4
	B	—	83.1	11.7	3.1	1.2	0.1	0.4	0.1	0.2	0.1
	C″	—	8.8	22.2	16.2	27.9	10.9	5.6	2.5	2.9	3.0
6	*A*	—	—	76.2	8.7	5.9	2.2	2.3	1.4	3.3	—
	B	—	—	95.3	2.2	1.5	0.4	0.4	0.1	0.0	0.1
	C″	—	—	40.8	14.5	20.5	10.2	6.0	2.5	2.7	2.8
16	*A*	—	60.8	14.2	8.1	5.8	3.0	2.9	1.6	1.9	1.7
	B	—	58.6	20.4	7.8	6.7	4.1	1.5	0.4	0.3	0.2
	C′	—	9.0	24.8	14.3	25.5	11.5	7.3	2.6	3.0	2.0
	C″	—	5.3	12.2	14.9	30.8	14.7	9.8	4.0	5.1	3.2
15	*A*	—	—	66.4	11.5	7.2	5.1	3.7	2.0	2.4	1.7
	B	—	—	81.1	7.7	6.2	2.5	1.5	0.5	0.3	0.2
	C″	—	—	17.5	15.7	29.4	14.8	10.4	4.4	4.0	3.8
8	*A*	—	—	70.8	13.6	6.5	2.9	1.9	1.1	1.5	1.7
	B	—	—	98.4	1.2	0.3	0.0	0.0	0.1	0.0	0.0
	C″	—	—	32.2	28.3	20.9	7.8	4.3	1.8	2.5	2.2
12	*A*	—	—	75.5	10.0	5.8	2.4	2.0	1.1	1.6	1.6
	B	—	—	92.0	6.4	1.3	0.1	0.1	0.0	0.0	0.1
	C′	—	—	26.3	27.7	26.9	9.1	5.0	1.4	3.6	—
	C″	—	—	15.2	25.7	30.9	13.5	6.6	2.2	3.4	2.5
1	*A*	—	—	53.3	19.5	9.7	6.3	4.4	2.5	2.4	1.9
	B	—	—	83.8	10.3	4.6	0.5	0.3	0.3	0.1	0.1
	C′	—	—	34.2	26.6	23.5	6.9	4.0	1.4	1.7	1.7
	C″	—	—	20.9	27.2	26.6	11.2	6.0	2.5	2.7	3.0
23	*B*	26.3	9.8	20.8	12.8	15.6	6.7	4.3	1.5	1.3	0.9
	C′	0.0	12.1	9.8	12.0	24.7	17.3	10.4	4.9	4.7	4.1
	C″	0.0	5.9	6.5	12.0	22.6	20.6	13.7	6.5	6.3	5.9
24	*A*	—	67.0	14.7	4.1	4.2	3.0	2.1	1.3	1.6	2.0
	B	—	28.0	18.0	16.0	18.9	9.7	5.3	1.7	1.6	0.8
	C′	—	7.9	11.0	10.5	24.9	18.2	13.8	5.2	4.9	3.6
	C″	—	5.6	7.5	9.6	22.5	21.0	14.7	6.8	7.0	5.3
22	*B*	—	—	54.8	14.9	15.4	6.8	4.8	1.6	1.0	0.7
	C′	—	—	13.7	14.0	24.1	19.5	14.9	5.4	4.7	3.7
	C″	—	—	10.3	10.7	20.7	21.4	17.8	7.3	6.4	5.4

A —Original coal.
B —Thermally treated coal.
C′ —Single drop-shatter of thermally treated coal.
C″—Double drop-shatter of thermally treated coal.

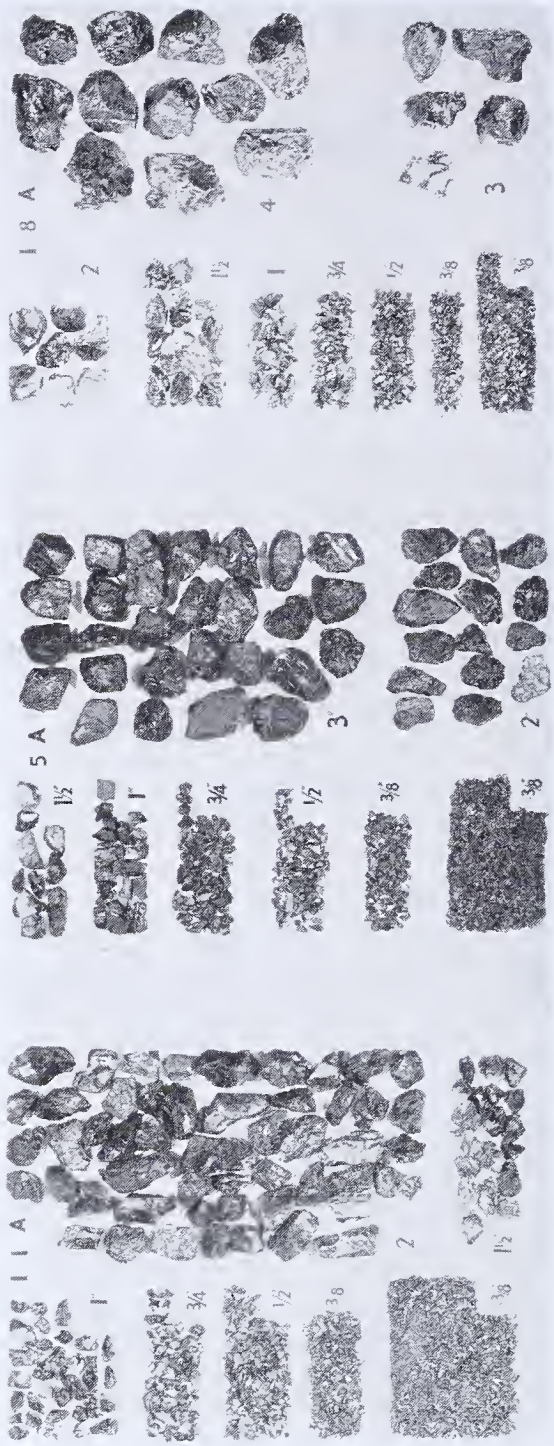


Fig. 3

Photographs of 50-pound samples of egg, broken, and grate-size anthracite after double drop-shatter

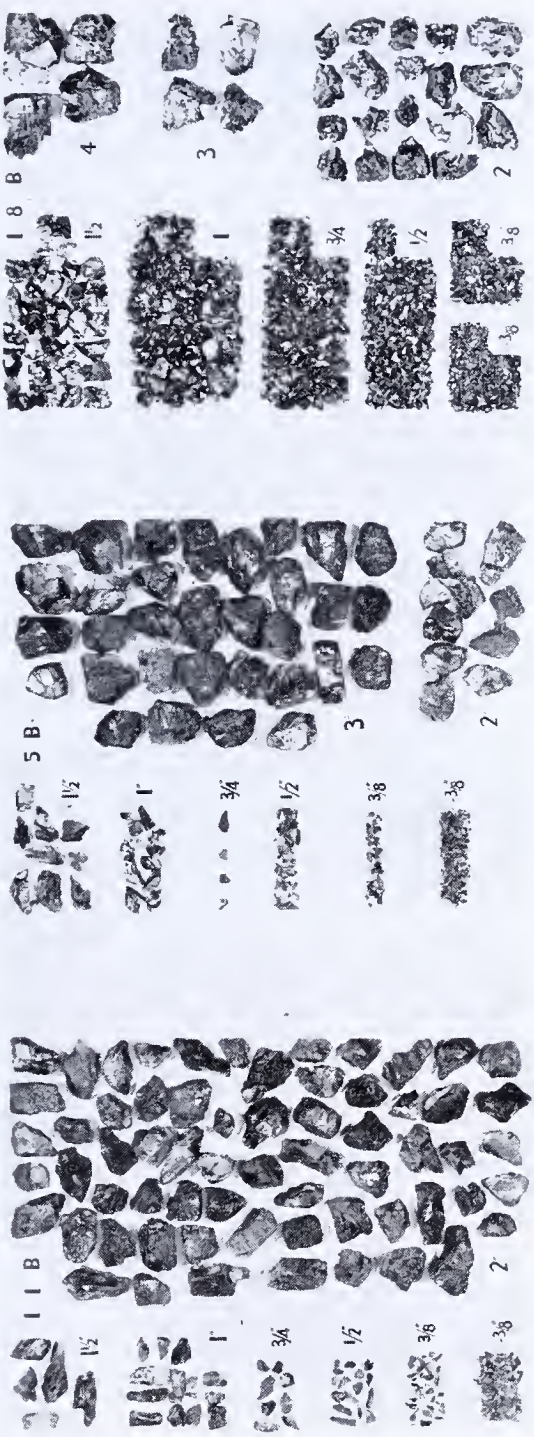


Fig. 4

Photographs of 50-pound samples of egg, broken, and grate-size anthracite after thermal treatment only

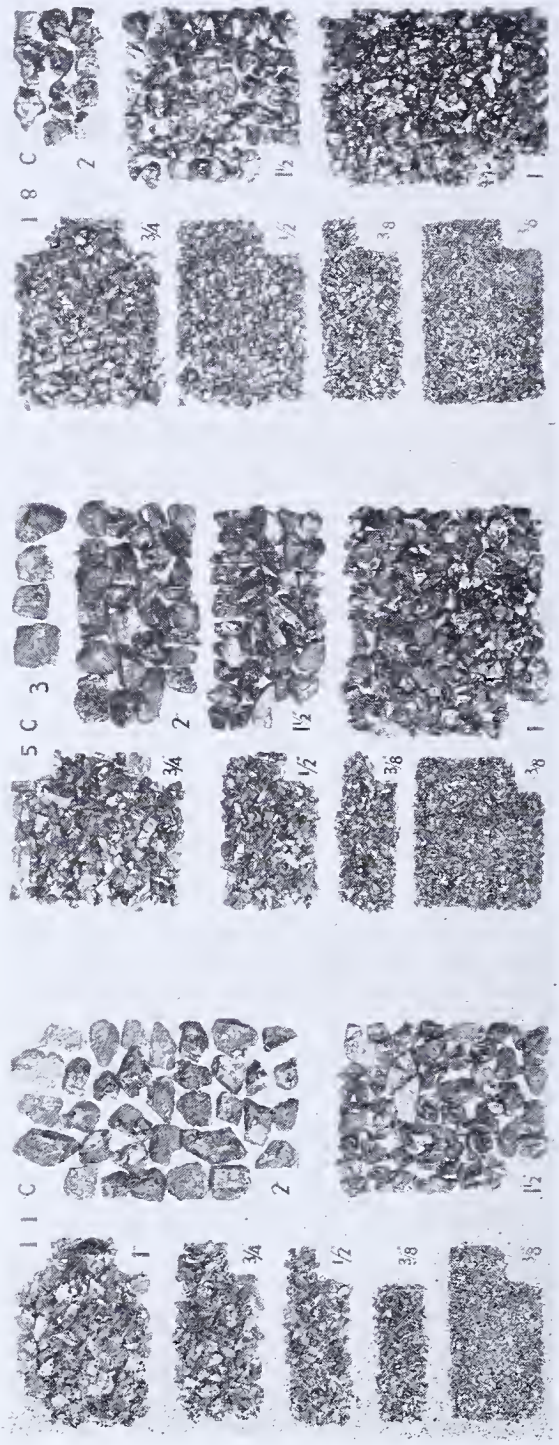


Fig. 5

Photographs of 50-pound samples of egg, broken, and grate-size anthracite after double drop-shatter of thermally treated coal

treatment to which the coal is subjected is substantially the same as outlined in the standard procedure. In down-run sets the coal is subjected to an added thermal shock once each cycle due to introduction of steam at about 250° F. Where reforming is employed an added thermal shock due to introduction of oil into the generator at 250° to 300° F occurs once each cycle, and in a few plants, using marginal blast in conjunction with heavy oil operation, higher generator temperatures are to be expected. Thus, it may be said that the standard procedure subjects the coal to substantially the heat treatment found in most generators, but somewhat less severe than found in the special cases. It may be said of the *B* pictures, therefore, that they illustrate the *minimum* amount of decrepitation that is to be expected with the various coals under the most favorable possible conditions of thermal and mechanical treatment.

The data and pictures for *C* treatment illustrate the total breakdown of the various coals resulting from thermal shock followed by the mechanical shock of the drop-shatter test previously described; the pictures show the results of the double drop. Since no two plants employ identical charging methods, the degree of mechanical shock to which the thermally treated coals are subjected varies considerably from plant to plant. These *C* pictures illustrate what might be expected under about the worst conditions that could be—and have been—encountered. For the majority of plants, however, the mechanical shock is considerably less than that producing the *C* fractions and the overall breakdown of the coal will fall at some point between the results illustrated for *B* and *C*.

Interpretation of Data

Having determined the amount of breakdown that may be expected for a variety of coals as a result of thermal and mechanical shock, the problem then arises as to the effect the breakdown will have upon water-gas operation. One coal has been found in which every piece of grate-size coal decrepitated as a result of thermal treatment, largely into egg, nut, and pea, with but a small percentage of buckwheat No. 4, while another coal in which only a few lumps broke up appreciably gave a relatively large (7 per cent) amount of buckwheat No. 4. Which of these coals is more suitable for water-gas operations?

Several possible methods of evaluating the results of these tests have been considered, and it was finally decided that some method should be used which would serve as an indication of relative behavior in a water-gas generator. For this purpose resistance of the fuel bed and quantity of potential blown-over fuel are of greatest importance, and the data have, therefore, been evaluated on this basis.

Table 3

Screen Analysis: Original Coal—Four Drops

Laboratory Sample Number	* *Treatment*	5″ x 4″	4″ x 3″	3″ x 2″	2″ x 1½″	1½″ x 1″	1″ x ¾″	¾″ x ½″	½″ x ⅜″	⅜″ x 4 Mesh	—4 Mesh
27	*A′*	73.0	11.2	9.2	2.7	1.3	0.8	0.6	0.3	0.5	0.4
	A″	63.9	13.3	9.7	4.3	3.2	1.5	1.2	0.7	1.1	1.1
	A‴	51.9	10.9	16.4	6.7	5.0	2.6	2.1	1.1	1.6	1.7
	A⁗	43.1	16.5	14.7	7.4	5.9	3.3	3.1	1.5	2.2	2.3
33B	*A′*	—	71.8	17.5	3.0	2.6	1.6	1.1	0.8	0.8	0.8
	A″	—	58.1	20.5	6.1	5.0	3.0	2.4	1.3	1.8	1.8
	A‴	—	51.7	21.8	6.1	5.5	4.3	3.1	2.1	2.7	2.7
	A⁗	—	40.1	27.6	6.4	7.1	4.5	4.2	2.8	3.6	3.7
33E	*A′*	—	—	81.5	6.2	5.4	2.4	1.6	0.9	1.1	0.9
	A″	—	—	69.5	11.1	6.9	3.6	3.1	1.8	2.1	1.9
	A‴	—	—	62.1	11.3	9.0	4.9	4.1	2.6	3.2	2.8
	A⁗	—	—	56.5	12.1	10.1	5.2	4.8	3.2	4.4	3.7

*
A′ —After 1st drop-shatter of original coal.
A″ —After 2nd drop-shatter of original coal.
A‴ —After 3rd drop-shatter of original coal.
A⁗—After 4th drop-shatter of original coal.

Furnas[8] in a comprehensive treatise on the flow of fluids through broken solids has shown that the variables affecting pressure drop are: (1) size composition of a bed of mixed sizes, (2) shape of particles, (3) degree of packing, (4) size of container, (5) rate of gas flow, (6) density of the gas, (7) viscosity of the gas, and (8) molecular weight of the gas. As a means of comparing coals, however, it is possible to eliminate a number of these variables since it is relative rather than absolute values that are of interest. Thus, for normal water-gas operation the rate of air flow is substantially the same for all plants operating at or near capacity, (197 cubic feet per minute per square foot of grate area, based on generator air volumes and grate areas, shown in *Bulletin 42*, Steere Engineering Company); the density, viscosity, and molecular weight of gas, although changing markedly at different parts of the cycle and varying throughout the generator, can for purposes of comparison be assumed constant since they will vary in substantially the same manner for each coal; the size of the container can be eliminated by making all calculations on the basis of a container with infinite diameter and correcting later for the specific generator for which the data are desired. Thus, for comparative purposes the variables can be reduced to the size composition of the coal in the fuel bed, and as data are available in the literature for the unit pressure drop through beds of different sizes of anthracite, the calculations are relatively simple.

In order to determine the size limits of blown-over fuel, samples were secured from a number of water-gas plants now using anthracite. Data for screen analyses of these samples are shown in Table 4, together with blast rates employed. There appears to be a considerable variation between plants in the size distribution of recovered blown-over fuel and this may be attributed largely to variations in the efficiency of the dust catcher and to variations in the method of operation of the sets. It appears probable from these data that the upper-size limit of true blown-over fuel is somewhere between 3 and 8 mesh. Were all the plants operating at the standard rate of 197 cubic feet per minute per square foot grate area, it is probable the data would indicate an upper limit of about 4 mesh.

Furnas[8] has shown that for iron ores, particles smaller than 14 mesh may be blown from the bed at blast velocities of 197 cubic feet per minute per square foot of grate area. At a given velocity, however, the lifting of particles will be roughly proportional to their density so that for anthracite the limiting size of particles lifted should be approximately 6 mesh.

[8]Furnas, C. C., *U. S. Bureau of Mines Bull.* 307 (1929).

Table 4

Screen Analyses of Blown-Over Fuel

(U. S. Standard Sieve Series)

PLANT	A	B	C	D	E	F	G*	H	I	J
Avg. Blast Rate (Cu. ft. per sq. ft. grate area per minute)	146	131	120	145	169	—	192	147	—	173
% On										
$\frac{3}{8}$"	0.0	0.0	11.1	1.1	1.0	0.2	0.0	1.2	0.4	1.5
# 3 Mesh	0.0	0.0	0.8	0.3	0.2	0.1	0.0	0.4	0.2	1.0
# 4 Mesh	0.4	0.0	1.3	1.6	1.7	0.2	0.0	1.9	1.5	3.7
# 6 Mesh	0.5	0.0	1.7	3.8	3.5	0.3	0.1	4.0	2.8	6.4
# 8 Mesh	1.6	0.4	3.2	7.5	8.1	1.3	0.2	9.0	4.0	12.6
#16 Mesh	27.8	18.6	19.6	36.5	37.6	26.5	17.6	37.3	17.2	23.8
#25 Mesh	15.3	16.6	9.8	11.5	11.8	14.5	14.3	11.5	7.8	20.0
Thru #25 Mesh	54.4	64.4	52.5	37.7	36.1	56.9	67.8	34.7	66.1	31.0
% of Fuel as Charged Recovered in Dust Collector	—	—	—	0.15	—	—	0.75	2.72	—	0.79

*No Dust Catcher, Collected at Stack.

On the basis of these two independent sets of data, therefore, it appears reasonable to assume that all material below 4 mesh in size may be considered as potential blown-over fuel.

Values for ΔP_x, the pressure drop in inches of water per foot height of coal column for a container of infinite diameter, have been calculated with the aid of data published by Furnas. The results of these calculations are presented in Table 5 and are based upon a rate of 197 cubic feet at standard conditions per minute per square foot of grate area. This table also shows the percentage of minus 4 mesh material resulting from the various treatments. Were no size degradation to occur the values of ΔP_x for grate, broken, and egg sizes would be 0.40, 0.54 and 0.72 respectively.

An examination of Table 5 shows that the pressure drop increase resulting from mechanical shock alone ranges from about 20 to 80 per cent and is greater in all cases the larger the initial coal size. Increase in pressure drop resulting from thermal shock alone shows an even wider distribution and varies from 2 to 170 per cent. In general, it is again true that for a given coal the greater increase occurs the larger the initial size, but the effect of initial size does not appear to be a controlling factor. The effect of indoor storage upon the resistance to thermal shock does not appear to follow any definite trend; in a few cases the increase in pressure drop is appreciable, in others, negligible. To secure conclusive data on this point, many more samples would have to be investigated and a more careful control placed upon initial and final moisture content, conditions of storage, and the selection of coals.

Although data were secured on single drop-shatter tests of the thermally treated coal for only about half the experiments, these data are sufficient to show that appreciable weakening of structure has occurred. The increase in pressure drop varies from 70 to 340 per cent. For the double-drop experiments, the increase varies from 80 to over 400 per cent showing the very wide spread in the properties of the thermally treated coals.

The relationship between time of heating and calculated pressure drop is shown for one coal in Fig. 6. It will be noted that while the decrepitation due solely to thermal shock, *B* curve, appears to be a straight-line function of the time of heating, the major weakening of the structure actually occurs during the first few minutes of treatment. This is proved by the C′ and C″ curves for single and double drop-shatter of the thermally treated coal. After this initial weakening, however, increase in pressure drop again becomes substantially a straight-line relationship with time of heating. These results suggest that some preliminary treatment could be given the anthracite which might overcome a major portion of the weak-

Table 5

Calculated Values of ΔP_∞ and Potential Blown-Over Fuel for Various Anthracites

Laboratory Sample Number	Remarks			ΔP_∞*				Per Cent Minus 4 Mesh			
	Field	*Size*	*Condition*	*A*†	*B*	*C'*	*C''*	*A*	*B*	*C'*	*C''*
18	Northern	Grate	Hard structure	0.70	1.08	1.74	2.00	0.8	0.6	2.5	3.8
17	Northern	Broken	Hard structure	0.83	1.13	1.74	1.99	1.1	0.5	2.4	3.7
20	Northern	Grate	Checkered structure	0.71	0.78	1.70	2.17	1.9	0.8	4.4	7.2
19	Northern	Broken	Checkered structure	0.97	0.89	1.78	2.18	2.5	0.8	4.5	7.0
13	Northern	Broken		0.82	0.75		1.78	1.1	0.3		6.0
14	Northern	Egg		0.97	0.84		1.81	1.2	0.2		3.4
7	Northern	Broken		0.84	0.64		1.51	1.1	0.1		3.2
7A	Northern	Broken	6 months stored	0.84	0.84	1.30	1.58	1.3	0.4	2.5	4.2
9	Northern	Egg		1.01	0.88		1.81	1.7	0.2		3.8
9A	Northern	Egg	6 months stored	0.95	0.90	1.37	1.90	1.4	0.3	2.5	3.9
10	Eastern Middle	Broken		0.82	0.62		1.45	1.4	0.3		3.1
11	Eastern Middle	Egg		1.08	0.77		1.34	1.6	0.1		3.1
11A	Eastern Middle	Egg	4 months stored	1.08	0.78	1.22	1.46	1.5	0.1	1.6	2.8
3	Eastern Middle	Egg		1.06	0.77		1.45	1.3	0.1		2.3
3A	Eastern Middle	Egg	6 months stored	1.15	0.76	1.22	1.49	1.5	0.0	1.6	2.9
5	Western Middle	Broken		0.79	0.61		1.45	1.4	0.1		3.0
5A	Western Middle	Broken	6 months stored	0.84	0.71	1.30	1.52	1.5	0.1	1.8	3.0
6	Western Middle	Egg			0.76		1.40		0.1		2.8
6A	Western Middle	Egg	6 months stored	1.02	0.77	1.32	1.61	1.6	0.1	1.7	3.1
16	Western Middle	Broken		0.91	0.79	1.46	1.80	1.7	0.2	2.0	3.2
15	Western Middle	Egg		1.13	0.86		1.74	1.7	0.2		3.8
8	Southern	Egg		1.04	0.73		1.31	1.7	0.0		2.2
12	Southern	Egg		1.02	0.76		1.48	1.6	0.1		2.5
1	Southern	Egg		0.89	0.79	1.24	1.46	1.9	0.1	1.7	3.0
23	Southern	Grate			1.03	1.85	2.18		0.9	4.1	5.9
24	Southern	Broken		0.89	1.19	1.85	2.27	2.0	0.8	3.6	5.3
22	Southern	Egg			1.14	2.02	2.33		0.7	3.7	5.4

*ΔP_∞—Inches of water pressure per foot of bed depth.
†*A* —Original Coal.
B —Thermally treated coal.
C' —Single drop-shatter of thermally treated coal.
C''—Double drop-shatter of thermally treated coal.

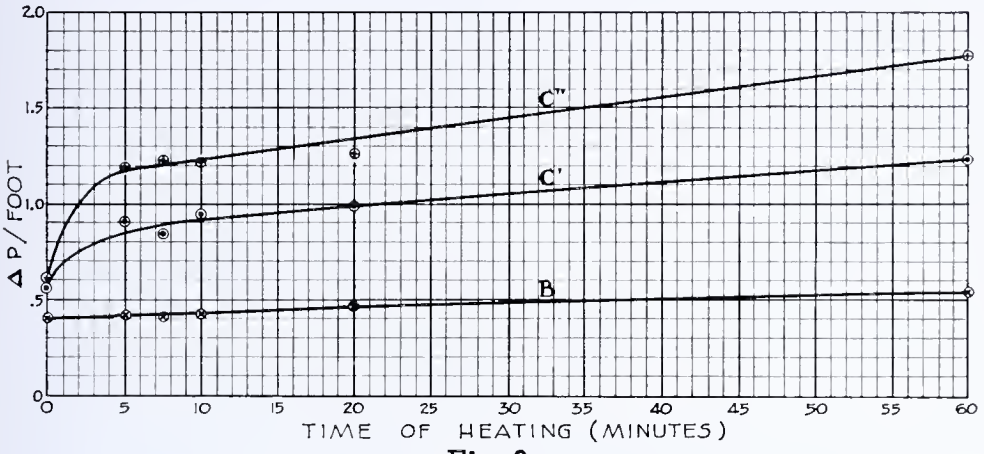


Fig. 6

Relationship between Calculated Pressure Drop and Time of Heating for a Sample of Grate-Size Anthracite

ening of the structure. Possibilities along these lines are being investigated.

As previously stated, the rated air velocities assumed in these calculations for pressure drop and blown-over fuel are such that minus 4 mesh material is potential blown-over fuel, hence this minus 4 mesh material does not enter into the calculations for pressure drop. For water-gas sets operating below the rated blast velocities, the size of fuel blown from the bed should be smaller and the percentage less than the figures shown in Table 5, but because the percentage of blown-over material is relatively small, this will not affect the size composition of the bed appreciably.

The relationship between rate of gas flow and pressure drop through a bed of broken solids is expressed by the following equation:

$$\Delta P = AR^B$$

where ΔP = pressure drop at desired conditions
A = pressure drop at standard conditions
R = rate of gas flow
B = constant for system, and usually varies between 1 and 2.

From this relationship it can be roughly estimated that if the blast velocity is only 50 per cent of normal rating, the pressure drop will be appreciably less than one-half of the figures shown in Table 5. Similarly, if the blast velocity is in excess of normal rating, the pressure drops will be appreciably higher.

Percentages of blown-over fuel recovered in actual water-gas operations are shown in Table 4 for a few plants. It will be noted

that these figures are, in general, considerably lower than the values for potential blown-over fuel shown in Table 5. This is readily understandable when one considers the nature of the process. Although all material below 4 mesh in size may be lifted from the bed, a portion of the smaller material is consumed by combustion before it has an opportunity to escape from the generator and the amount so consumed will be proportionately larger the smaller the size of the material. Furthermore, the very fine sizes will not be removed by the angle-connection dust catcher commonly used on water-gas machines so that the percentage of recovered material is progressively less the smaller the size. These conclusions are in agreement with the screen analyses of the blown-over fuel from the various plants which show a maximum concentration at a size in the vicinity of 16 mesh.

From the data thus far secured, there appears to be no advantage to be gained by preparing sizes larger than broken for the water-gas market because, of the larger sizes tested, all decrepitated more severely than did broken and egg to produce in the generator substantially the same pressure drop through the bed. It is possible, however, that a few of the more resistant coals which were not available for test in grate size should be tested for possible use in very large water-gas sets. This, however, would be of interest only if the particular collieries were equipped to produce that size and had the opportunity of marketing the coal to a gas company operating large water-gas sets.

The foregoing experiments and discussion have been based upon the premise that the original coal is of uniform size when entering the water-gas generator. Unfortunately, such is not the case in many instances where handling of the coal prior to charging produces size degradation. Since it would be undesirable to determine complete decrepitation data on all the numerous combinations of size distribution resulting from various handling treatments, this matter has been given theoretical consideration. It has been found that reasonably accurate predictions can be made of both fuel-bed resistance and blown-over fuel from decrepitation data on standard sizes of fuel and size-distribution of the coal in question. The method used involves only the correction of the decrepitation data for the percentage of other sizes originally present. This method gives satisfactory results because, in general, the amount of decrepitation decreases as the size of coal particles decreases, so that neglecting decrepitation of sizes below egg does not introduce an appreciable error.

The analyses reported in Table 1 for thermally treated coal show moisture contents of 0.4 to 2.0 per cent and volatile matter contents

of 2.0 to 3.9 per cent. In view of the fact that these samples had all been subjected to a heat treatment at 1400-1500° F, the result was unexpected. The moisture content could be readily accounted for by adsorption during dry quenching, grinding, and sampling for analysis, but it appeared improbable that volatile matter could be accounted for in such a manner. An experiment was performed, therefore, to determine whether all the volatile matter could be eliminated by heating to 1400° F in the manner employed for the thermal treatment. The procedure used was as follows:

A one-gram sample of minus 60 mesh coal was placed in a standard covered platinum volatile-matter crucible and heated to 1400° F in the standard volatile-matter furnace at the heating rate for decrepitation tests. Loss in volatile matter was determined in the usual manner and the same sample was then subjected to the standard volatile-matter determination at 1720° F. Results of these tests are shown in Table 6 for one coal from each of the four major fields, together with the results of standard A.S.T.M. moisture and volatile-matter results on the same samples.

Table 6

Coal	*Per cent Water A.S.T.M.*	*Per cent Vol. Matter at 1400° F.*	*Per cent Additional Vol. Matter at 1720° F.*	*Per cent Total Vol. Matter*	*Per cent Total Vol. Matter A.S.T.M. at 1720° F.*
3A	3.5	2.0	1.8	3.8	3.3
14A	2.6	3.4	2.1	5.5	5.4
16A	2.3	3.7	1.8	5.5	5.3
24A	0.9	6.1	2.7	8.8	8.0

These data indicate that heating at 1400° F, even for the prolonged times employed, removes only 60 to 80 per cent of the volatile matter that is obtained by the standard A.S.T.M. procedure. Furthermore, it should be noted that in all cases the combination of prolonged heating followed by standard volatile determination gave a higher total volatile content.

CORRELATION WITH PLANT-SCALE TESTS

In the preceding sections, data have been presented to show the pressure drops that would result from the passage of air, at a velocity of 197 cubic feet per minute at standard conditions per square foot of grate area, through beds of anthracite having the size distribution found after various treatments of the coal. These calculated data are directly applicable for comparison of different coals as to their suitability for processes involving deep fuel beds, but it must be borne in mind that they are not directly applicable to calculation of absolute pressure drops through fuel beds in which combustion is taking place.

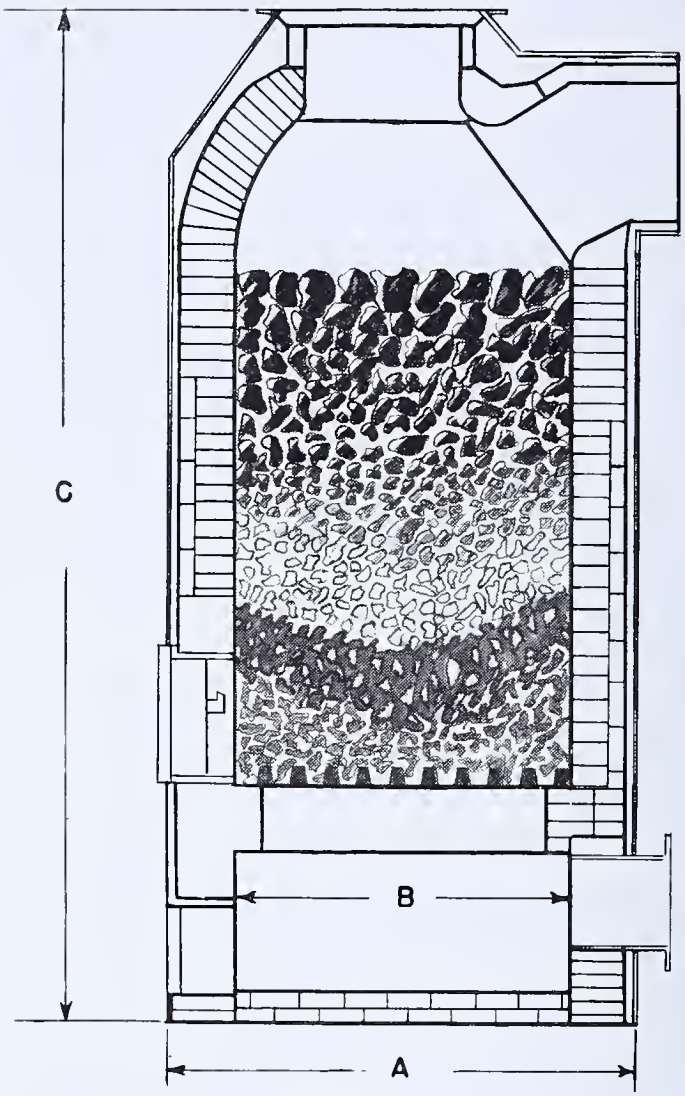


Fig. 7

Diagrammatic Cross-Section View of Water-Gas Generator Showing Size Composition of Fuel Bed and Dish-Shape Clinker

As can be seen from a study of Fig. 7, the size composition of the fuel in such a bed will vary from top to bottom, and the fuel itself is supported on an ash or clinker layer. Temperatures throughout the bed will, of course, vary over wide limits from substantially room temperature below the grate to almost 3000° F at the zone of intense combustion just above the clinker. Thus, it is apparent that for a calculation of theoretical pressure drops through the entire bed all of the factors enumerated in the previous section must be considered, i.e., size composition of bed, shape

of particles, degree of packing, size of container, rate of gas flow and density viscosity and molecular weight of the gas.

During the course of plant-scale tests, it has been possible to secure all the necessary data whereby calculations of overall pressure drops throughout the entire bed can be made and compared with experimental values. In order to facilitate these calculations, certain assumptions have been made which are substantiated by experimental data secured during the tests or by published data available in the technical literature. Thus, it has been assumed that the temperature throughout the active combustion zone is approximately 2850° F and that this zone is approximately 18 inches deep and immediately above the clinker level. The size of the fuel at this point was determined by actual screen analysis of a 100-pound dry-quenched sample and is shown in Table 7.

Table 7
Size Composition of a 100-Pound Sample of Fuel Immediately Above Clinker Level

SIZE (INCHES) *Square-Hole Screens*	SIZE (INCHES) *Round-Hole Equivalent*	*Percentage*
4 x3	5 x3 7/8	1
3 x2	3 7/8 x2 1/2	7
2 x1 1/2	2 1/2 x1 7/8	8
1 1/2 x1	1 7/8 x1 1/4	20
1 x 3/4	1 1/4 x 15/16	17
3/4 x 1/2	15/16 x 5/8	18
1/2 x 3/8	5/8 x 1/2	9
3/8 x4 mesh	1/2 x 1/4	9
Minus 4 mesh	Minus 1/4	11

The temperature of the bed above this zone at the end of the blast period in the cycle immediately preceding a fresh charge is assumed to decrease progressively to about 1800° F immediately below the layer of fuel last charged, and the temperature of this last charged fuel is by experimental measurement approximately 1475° F. The size composition of the fuel last charged will be substantially that of the original coal unless appreciable decrepitation occurs. That of the layer beneath it will be approximately equivalent to thermally treated coal subjected to a single drop-shatter and the next layer immediately beneath this will have a size composition equivalent to thermally treated coal subjected to a double drop-shatter. The remaining portion of the bed should not be affected appreciably by introduction of fresh charges and should vary in size from that of double drop-shattered coal to that found in the active combustion zone.

Experimental determinations of the overall pressure drop through the bed have been made immediately preceding and after

removal of clinker for a large number of clinkering cycles. For the particular conditions of this test, the data show a clinker resistance equal to 6 inches pressure drop per foot of clinker depth. This value will, of course, vary with the coal and the conditions of operation, but is substantially correct for the particular test being considered.

Likewise, experimental determination of pressure drop increase due to the addition of a fresh charge has been made over a great many charging cycles. This increase is the result of two factors: resistance of the new coal itself and that due to the decrepitation of thermally weakened coal already present in the generator. In Table 8 are shown data for calculated values of ΔP_∞ and ΔP determined from laboratory studies on decrepitation, and experimentally determined values of ΔP obtained for averages of plant test data.

Table 8
Calculated and Determined Pressure Drops
Inches of Water Pressure per Foot of Bed Depth

	ΔP_∞	ΔP (1)
Laboratory Determination(2)		
Coal as Charged	0.7	0.6
Thermally Treated Coal	0.8	0.7
Thermally Treated Coal, Single Drop-Shatter	1.4	1.3
Thermally Treated Coal, Double Drop-Shatter	1.6	1.5
Plant Tests		
Total Pressure Drop Increase		1.2
Increase Due to Added Coal(3)		0.5
Increase Due to Decrepitation		0.7

(1) $\Delta P = (\Delta P_\infty)$ (f)

where f is the factor for wall effect determined from the ratio between the diameters of particles and container.

(2) Uncorrected for temperature of the gas. Corrections would reduce all valves by approximately 0.1.

(3) The increase due solely to added coal was determined as indicated in Table 9.

Based upon the foregoing data and assumptions, the following calculations have been made for the various pressure drops throughout a generator fuel bed. These calculations are based upon data for the twenty-third run of a day's operation when conditions in the generator were believed to be substantially stable. Actual pressure drop through the generator, corrected to the standard blast rate, averaged over a large number of tests for the twenty-third run, showed a drop of 16.3 inches. The calculated pressure drop and the data upon which the value was obtained are shown in Table 9 and amounts to 15.7 inches. Although data have been reported to the nearest one-tenth for average values, actual determinations in plant operation are made to only the nearest 0.5 inch and it is questionable whether any of the data are more accurate than this.

Table 9

Calculations of Data for Pressure Drop Through Water Gas Generator

Layer Number	*Height Above Grate (Inches)*	$B_{25°C.}$ (1)	$A_{\infty 25°C.}$ (2)	B_t (3)	$A_{\infty t}$ (4)	$\Delta P_{\infty t}$ *In./Ft.*	*Wall*(5) *Effect Factor*	ΔP_t *In./Ft.*	*Total* ΔP *Inches*
1	0 - 12							6.0	6.0
2	12 - 30	1.69	10.72	1.23	3.22	2.63	0.98	2.6	3.9
3	30 - 54	1.75	9.81	1.30	2.84	1.71	0.94	1.6	3.2
4	54 - 66	1.82	8.72	1.38	2.53	1.27	0.89	1.1	1.1
5	66 - 78	1.86	8.00	1.43	2.56	1.14	0.88	1.0	1.0
6	78 - 90	1.93	4.81	1.56	1.78	0.60	0.83	0.5	0.5
									Total 15.7

(1) From size distribution and data by Furnas.

(2) Calculated from equation: $\Delta P_\infty = A_\infty R^B$.

(3) From curves by Furnas.

(4) From curves by Furnas.

(5) From data on anthracite by Furnas.
$R = 0.1$ cc./sec./sq. cm. $= 197$ cu. ft./min./sq. ft.

SUMMARY

A laboratory method is described in detail whereby the size stability of anthracite which has been subjected to thermal and mechanical shock can be determined. The conditions of shock chosen for this test simulate closely those experienced by water-gas generator fuel. Detailed data are shown for the size composition of a variety of grate, broken, and egg-size anthracites after varying shock treatments.

Data are shown for the effect of from one to four drops in the standard drop-shatter test for comparison with size stability data on coke. Curves are also shown which indicate the effect of time of heating upon the size stability and ability of the coal to withstand subsequent mechanical shock.

For purposes of application to deep fuel beds, the data have been calculated to indicate relative fuel-bed resistance and amount of potential blown-over fuel for blast rates normally experienced in water-gas generators. Data are shown for size composition and amount of blown-over fuel obtained in a number of water-gas plants using anthracite, and reasons presented to show why only a small percentage of potential blown-over fuel is actually recovered as such in plant practice.

Calculated and experimental data for increase in pressure drop through a water-gas generator resulting from decrepitation of the coal as presented, and show excellent agreement. The experimentally determined values agree closely with the results for single drop-shatter by laboratory test methods.

Calculated and experimental data for overall pressure drop through a water-gas generator are presented and show substantial agreement, a further indication that the results of laboratory test are indicative of actual plant results.

It is apparent from the data presented that decrepitation due to thermal and mechanical shock combined is not in most instances a serious factor in water-gas sets operating under normal conditions. Clinker resistance appeared to be a much more important factor in influencing overall resistance. For the majority of plants which now operate at blast rates equal to or lower than the rated normal of 197 cubic feet per minute per square foot of grate area, the majority of the anthracite tested would give little or no trouble from decrepitation.

Where conditions of operation of a water-gas set are such that they differ markedly from those of the standard laboratory procedure, as for example where marginal blast is employed with subsequent higher temperatures at the top of the generator, the thermal shock treatment could be modified to suit the desired conditions. Experimental data indicate, however, that the relative stability of the various coals is not materially changed by changes in conditions of treatment although absolute values will, of course, change.

PUBLICATIONS OF THE MINERAL INDUSTRIES EXPERIMENT STATION

Research results of the experiment station are disseminated through the following publications: (1) Bulletins which present the proceedings of technical conferences, and the detailed results of experimental studies of a comprehensive problem. (2) Information circulars which present in nontechnical language the results of studies which are given in greater detail in other publications, and statistical data or pertinent information gathered from other sources. (3) Technical papers consisting of bound copies of papers published in scientific journals, of progress reports, and of results of experimental studies representing isolated phases of research later to be published in bulletin form.

A few of the publications are listed below. These may be obtained from the Director of Mineral Industries Research, The Pennsylvania State College, State College, Pa., at the price quoted.

Bulletins

15. Proceedings of the Third Pennsylvania Mineral Industries Conference, *Coal Section,* held at The Pennsylvania State College, November 10-11, 1933. 62 pages, with 6 illustrations. *Price 50 cents.*

23. The Chemistry of the Petrographic Constituents of Bituminous Coal. Part I. Studies on Fusain, by Walter Fuchs, A. W. Gauger, C. C. Hsiao, C. C. Wright. 1938. 43 pages, with 12 illustrations. *Price 50 cents.*

27. Problems and Trends in the Mineral Industries of Pennsylvania, by W. M. Myers. 1939. 77 pages, with 24 illustrations. *Price 50 cents.*

Technical Papers

5. Utilization of Coal and Scientific Research, by A. W. Gauger. 1933. 9 pages. *Price 10 cents.*

8. The Hydrogenation of Coal, by C. C. Wright and A. W. Gauger. 1934. pp. 164-169. *Free.*

13. Mineral Matter in Coal. A Preliminary Report, by A. W. Gauger, E. P. Barrett, and F. J. Williams. 1934. 10 pages. *Price 10 cents.*

16. A Furnace for the Measurement of Coal-Ash Softening Temperature, by Elliott P. Barrett. 1935. 10 pages, with 5 illustrations. *Price 10 cents.*

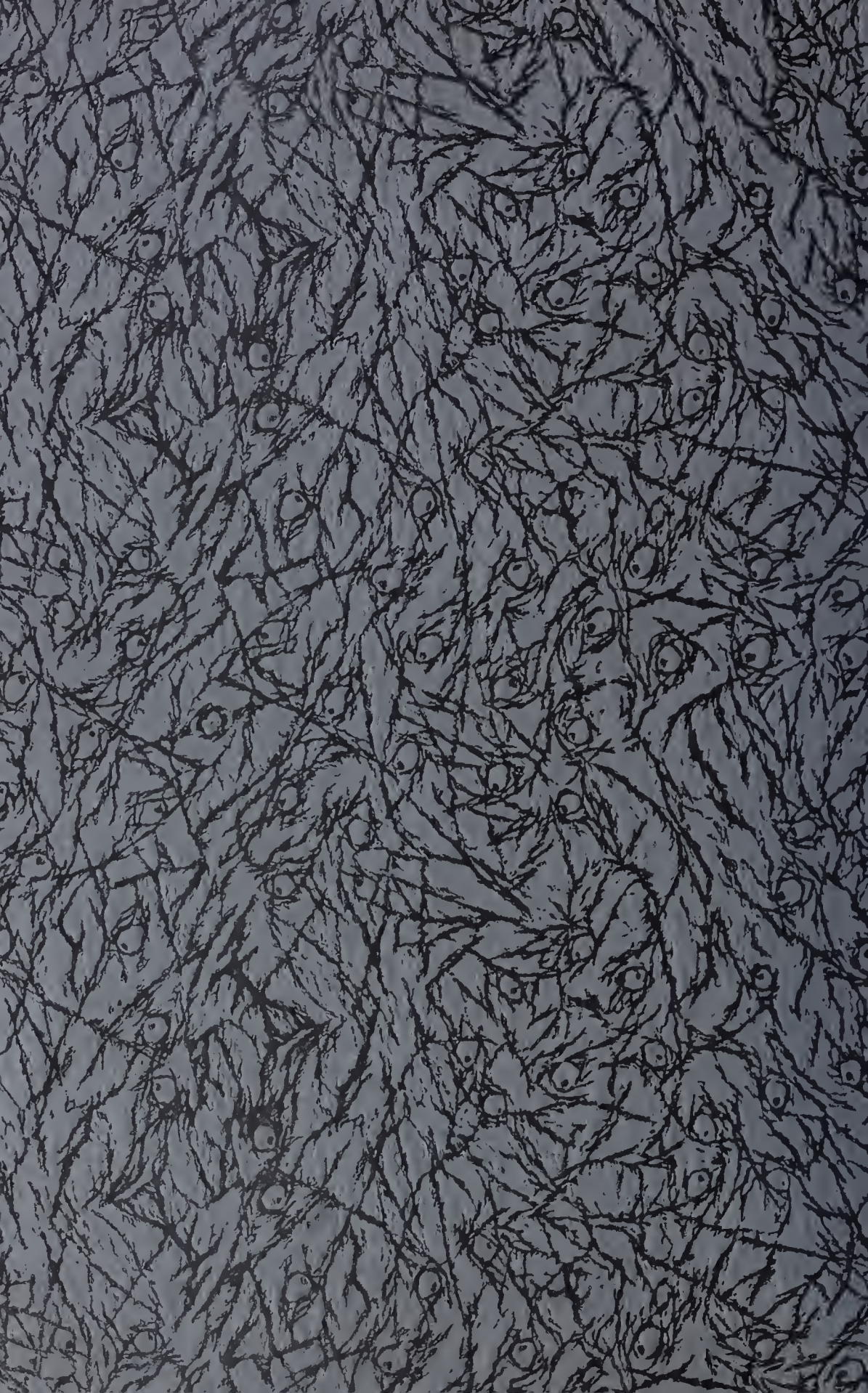
39. The Significance of Ash Softening Temperature and Ash Composition in the Utilization of Coal, by A. W. Gauger. 1938. pp. 376-401. *Price 10 cents.*

46. Anthracite Region of Pennsylvania, by R. E. Murphy and M. Murphy. 1938. 10 pages, with 10 illustrations. *Price 25 cents.*

57. Plans and Progress of Anthracite Research, by A. W. Gauger and C. C. Wright. 1940. 15 pages, with 9 illustrations. *Free.*

Circulars

6. The Functions of Pennsylvania's Mineral Industries Experiment Station. 1935. 30 pages, with 13 illustrations. *Free.*

8. Vocational Guidance in the Mineral Industries. 1936. 64 pages, with 72 illustrations. *Free.*

11. Mineral Industries Correspondence and Extension-Class Instruction. 1938. 20 pages, with 2 illustrations. *Free.*